# Bell Labs Nanotechnologies, Hope or Hype? An Edge for the Warfighter?

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**LGS COO/CTO**
**Alcatel-Lucent Technologies**



# Outline

- **Underlying Nano-Technologies**
- **Some Examples of Current Research:**
  - ***Cell Phone Nanotechnologies***
  - ***Optical Systems***
  - ***Chemical Sensors-"Dog on a Chip"***
  - ***DNA Analyzer***
  - ***Nano Gecko Hair***
  - ***Chemical Factories on a Chip***
  - ***Quantum Computers***
  - ***Doing Science with Nanotechnology***
  - ***Sensor Networks***
- **The Future**

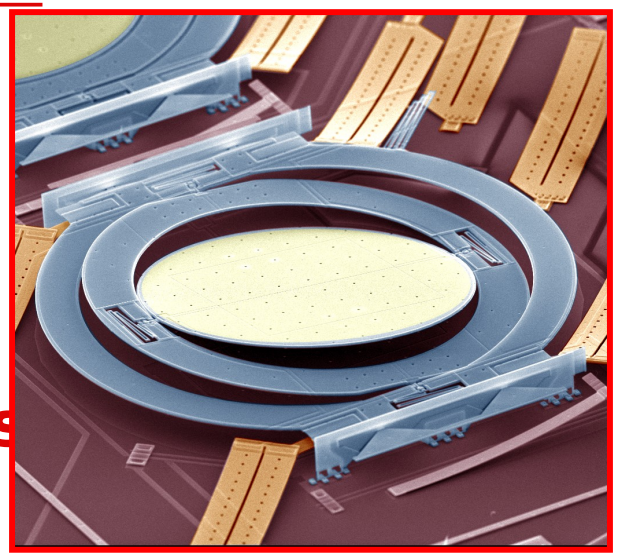
## Technologies:

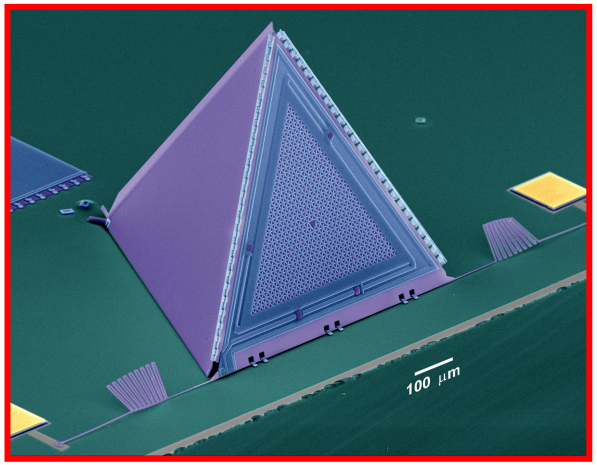
- MEMS/Nanotechnologies
- High Speed Electronics
- Quantum Cascade Lasers
- InP Optoelectronics
- SiOB

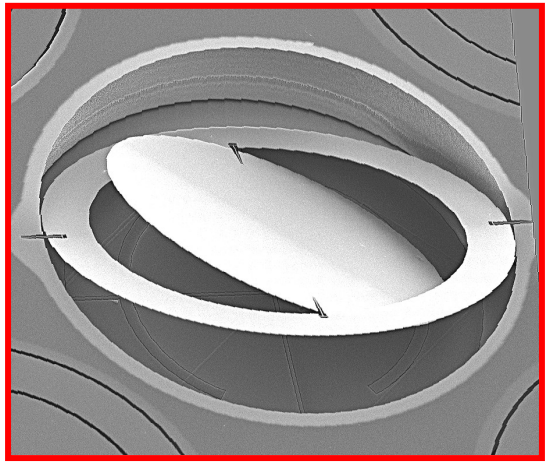
# MEMS-Micro Electrical Mechanical Systems

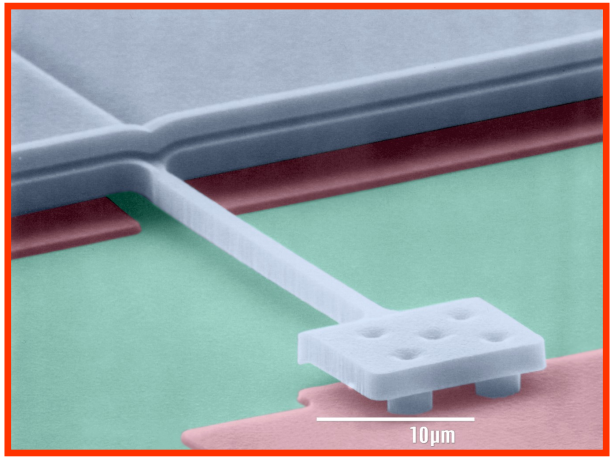
**Devices with small (< µm) and movable structures fabricated with integrated circuit technology**

**=>small, fast, cheap and robus**

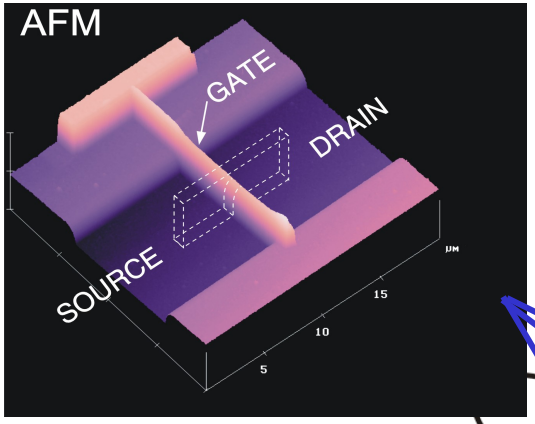




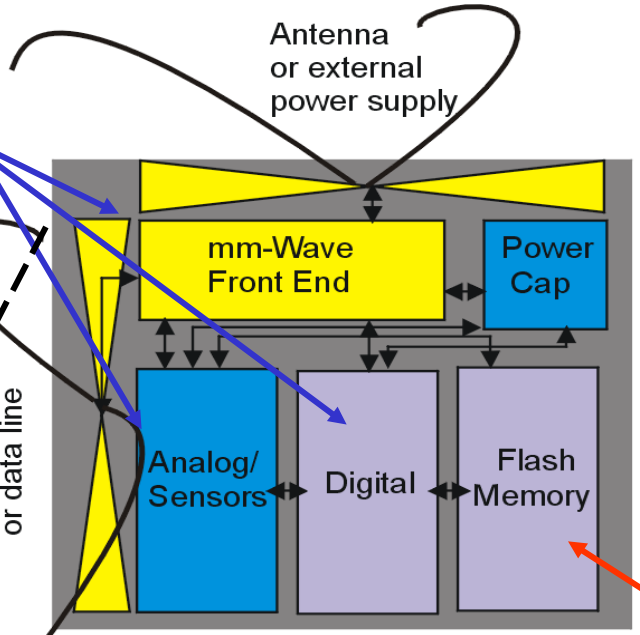


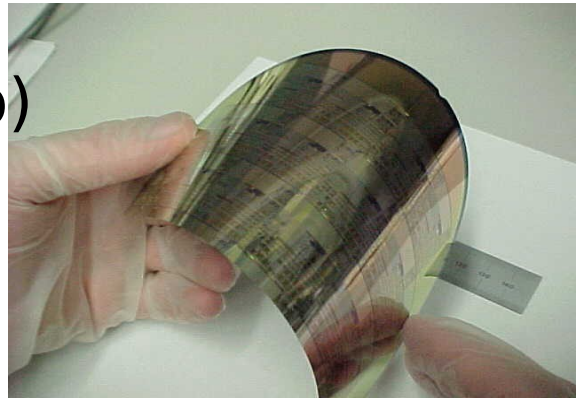
# Micrometer-scale IC's: A real "Cell" Phone




Nanotransistor

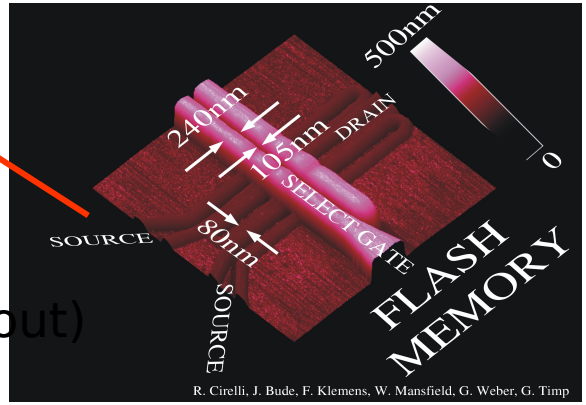
(system on a μchip)



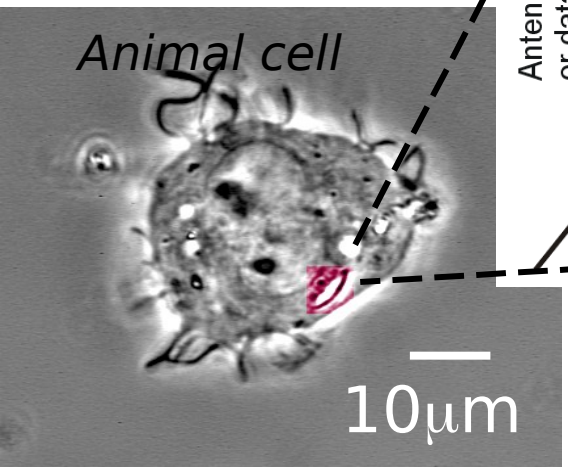



~10μm thick 200mm wafer with circuits

sub-100nm Flash Memory




193nm Lithography



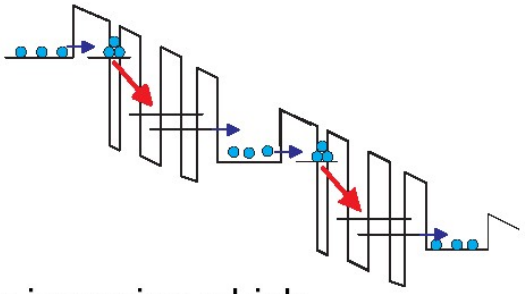

100μm

(mm-wave ID TAG chip layout)

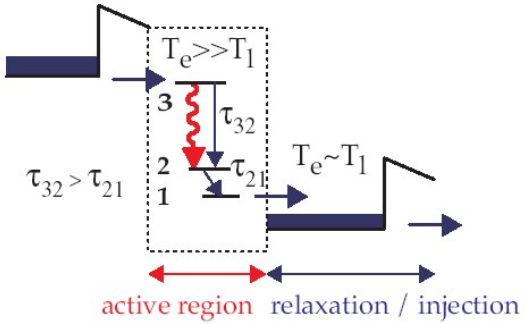
# QCL's-Bright IR Flashlights

## Quantum cascade lasers

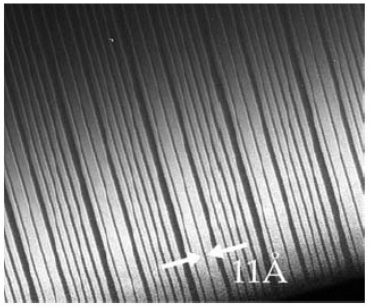
- **Cascade**
  - each e- emits N photons



- **Active region / injector**
  - active region → population inversion which must be engineered
  - injector → avoid fields domains and cools down the electrons



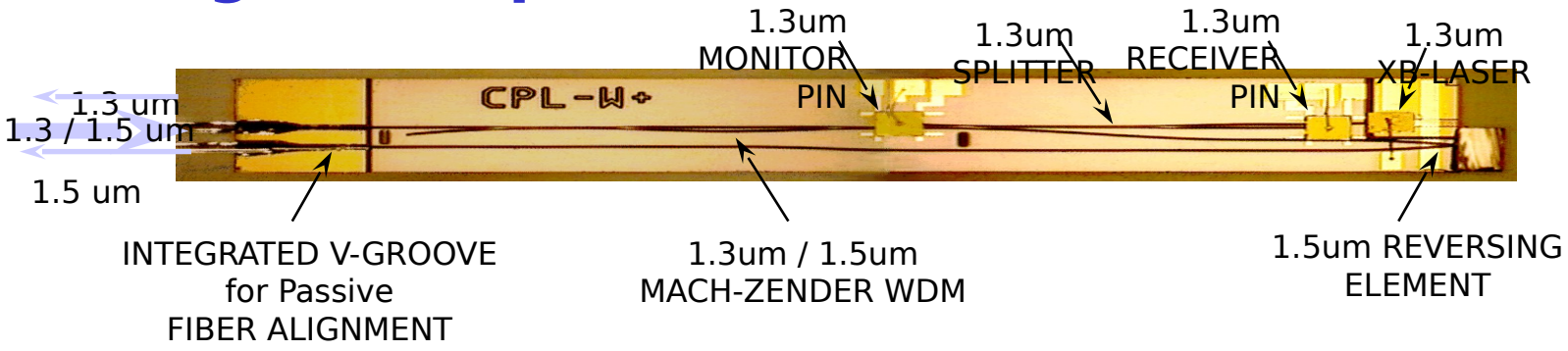

- **MBE**
  - growth of thin layers
  - sharp interfaces



# Optics-Tomorrow's Technology

- **Bell Labs has been developing hybrid integration technologies:**
  - **Passive alignment**
  - **PLC technologies**
  - **Wafer scale assembly**
  - **Module packages that are non-hermetic**
- **We can now also integrate advanced active components:**
  - **Laser diodes**
  - **Photodiodes**

⇒ **Integrated optical modules:**



# Some Representative Examples:

- Cell Phone Nanotechnologies
- Optical Systems
- Chemical Sensors-”Dog on a Chip”
- DNA Analyzer
- Nano Gecko Hair
- Chemical Factories on a Chip
- Quantum Computers
- Doing Science with Nanotechnology
- Sensor Networks

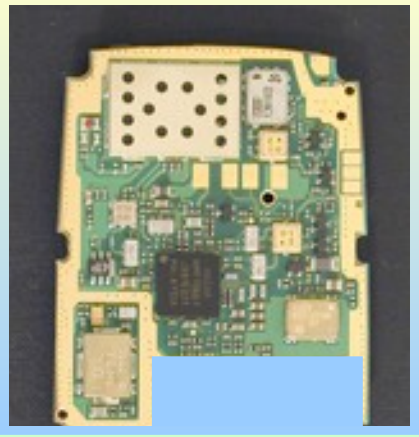
# Nanotechnology will Revolutionize Handheld RF Appliances

- The mantras of nanotechnology, e.g. small, light, cheap are the business imperatives for manufacturers in this space.
- Nanotechnology enables new functionality that can't be implemented in a hand held device using macro versions of the technology.
- Nano solutions in general tend to be much lower power than their conventional counterparts. In hand-held appliances, battery life is key.
- Cell phones will exhaust Moore's law sooner than almost any other application. Nanotechnology is the land beyond the end of the roadmap. For Bell Labs this is not "terra incognita".

# Bell Labs has Many Advanced Solutions

- Blast Antennas
- Projection Displays
- RF Components
- Liquid Lenses
- Advanced Sensors
- Batteries
- Microphones

# RF Components are Relatively Expensive



**RF BOM : $17.25**

**Dataquest Estimate: $24.20**

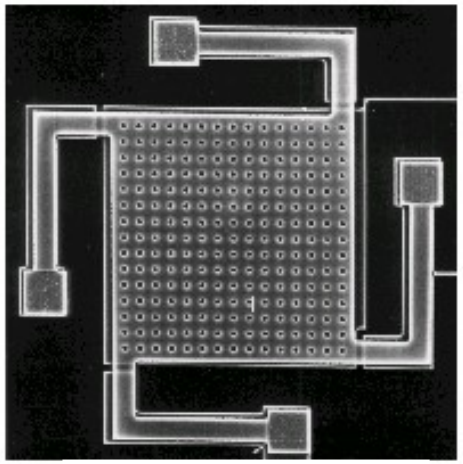
an opportunity

**RF MEMS**

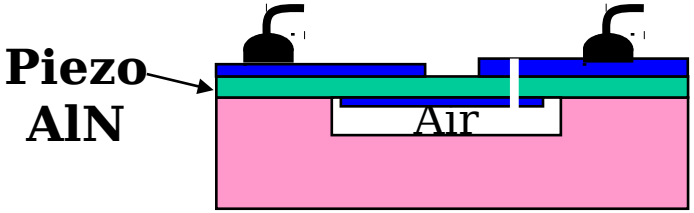
| Circuit Block | Part no. | Description | Qty. | Unit Cost | Total Cost | Block Cost | Count |
|---|---|---|---|---|---|---|---|
| **Front end** | | T/R switch | 1 | 1.54 | 1.54 | | |
| | | Dual band RX S | 1 | 1.44 | 1.44 | | |
| | 402 | Discretes | 7 | 0.0021 | 0.0147 | **2.99** | **9** |
| | | Inds | 4 | 0.035 | 0.14 | | |
| **Receiver** | | LNA 900 | 1 | 0.3 | 0.3 | | |
| | | LNA 1800 | 1 | 0.3 | 0.3 | | |
| | | Trans | 2 | 0.05 | 0.1 | | |
| | | Dual band RX S | 1 | 1.44 | 1.44 | | |
| | | Discretes | 24 | 0.0021 | 0.0504 | | |
| | | Balun 1800 | 1 | 0.15 | 0.15 | | |
| | | Balun 900 | 1 | 0.15 | 0.15 | | |
| | | **Transceiver** | **1** | **2.78** | **2.78** | | |
| | | Balun 1800 | 1 | 0.15 | 0.15 | | |
| | | Balun 900 | 1 | 0.15 | 0.15 | | |
| | 402 | Discretes | 58 | 0.0021 | 0.1218 | | |
| | 603 | Discretes | 10 | 0.0021 | 0.021 | | |
| | 805 | Discretes | 1 | 0.0021 | 0.0021 | **5.72** | **103** |
| **LO** | | VCO | 1 | 1.28 | 1.28 | | |
| | | Balun | 1 | 0.15 | 0.15 | | |
| | 402 | Discretes | 9 | 0.0021 | 0.0189 | | |
| | 603 | Discretes | 0 | 0.0021 | 0 | | |
| | 805 | Discretes | 1 | 0.0021 | 0.0021 | | |
| | | Tant cap | 1 | 0.064 | 0.064 | **1.52** | **13** |
| **TX PA** | | PA | 1 | 2.67 | 2.67 | | |
| | | Coupler | 1 | | 0 | | |
| | | Diode detector | 1 | | 0 | | |
| | | TX buffer | 1 | 0.334 | 0.334 | | |
| | | Dual TX filter | 1 | 1.5 | 1.5 | | |
| | | TX filter 900 | 1 | 0.65 | 0.65 | | |
| | 402 | Discretes | 30 | 0.0021 | 0.063 | | |
| | 603 | Discretes | 1 | 0.0021 | 0.0021 | | |
| | 805 | Discretes | 2 | 0.0021 | 0.0042 | | |
| | | Ind coil | 1 | 0.035 | 0.035 | **5.26** | **40** |
| **TCXO** | | TCXO | 1 | 1.39 | 1.39 | | |
| | | Trans | 1 | 0.15 | 0.15 | | |
| | 1208 | Cap | 1 | 0.06 | 0.06 | | |
| | 402 | Discretes | 10 | 0.0021 | 0.021 | | |
| | 805 | Discretes | 1 | 0.0021 | 0.0021 | **1.62** | **14** |
| | | **Total** | **183** | | **$17.25** | | |

Notes:
High comp count although DCR RX. Second stage RX SAW's, and external LNA's. Matching comps and baluns inc count.
TX is direct modulation. Filter saved on DCS.

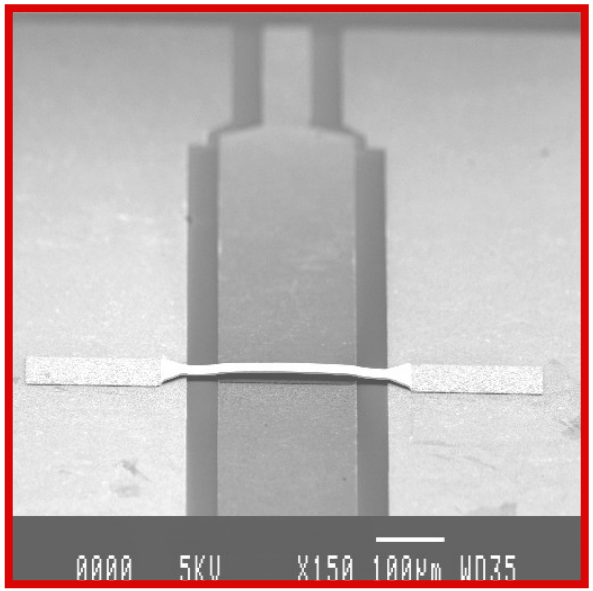
# Bell Labs MEMS RF Components



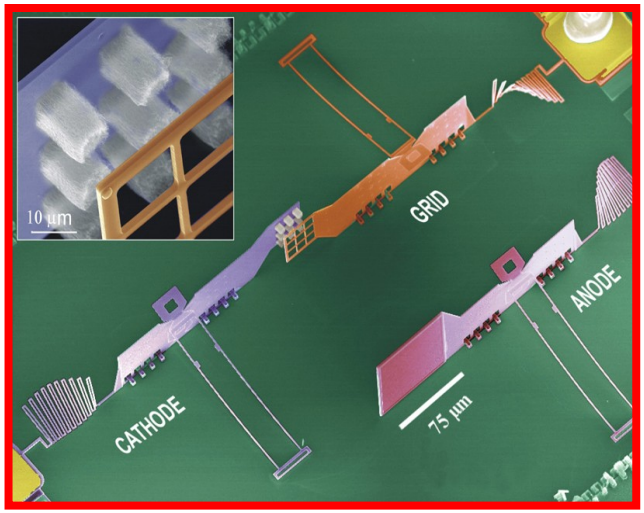
Capacitors



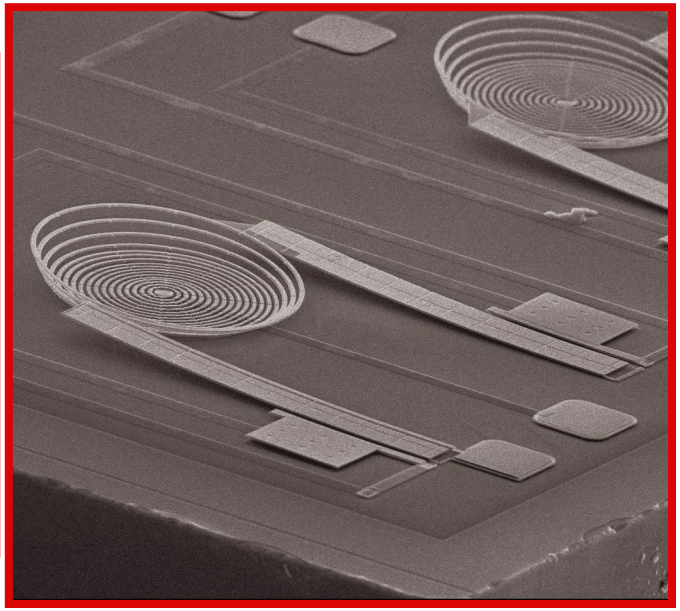

Filters




RF Switches

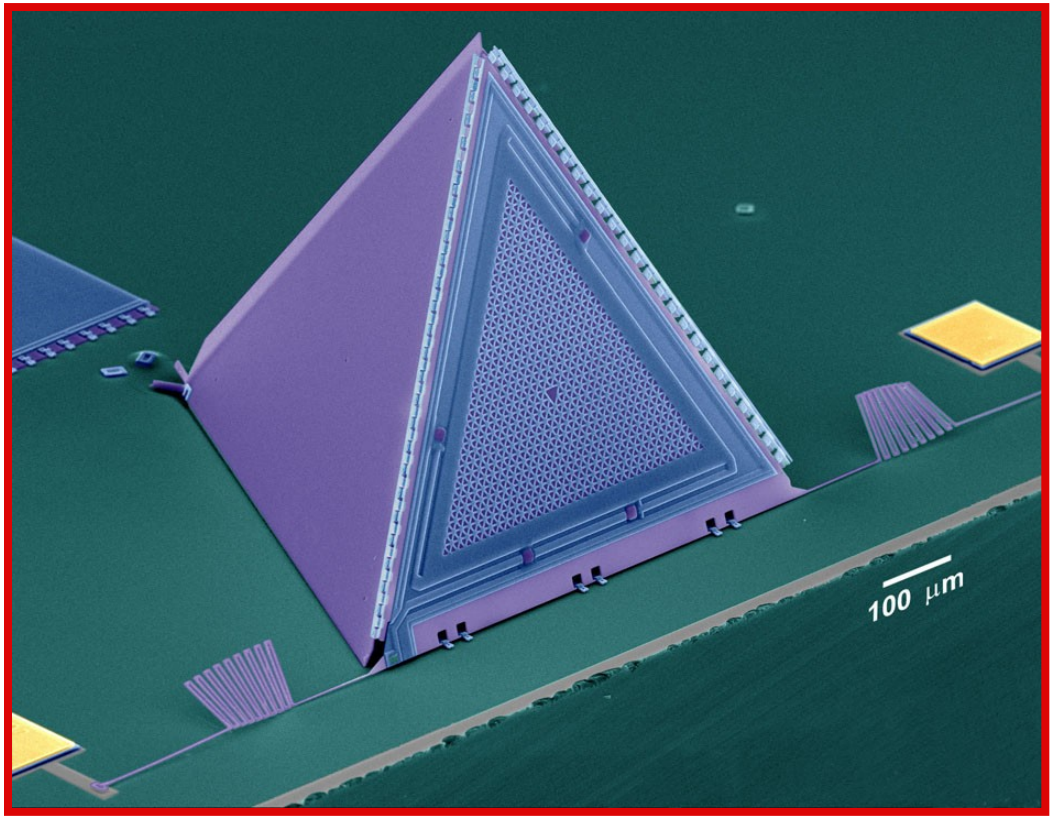


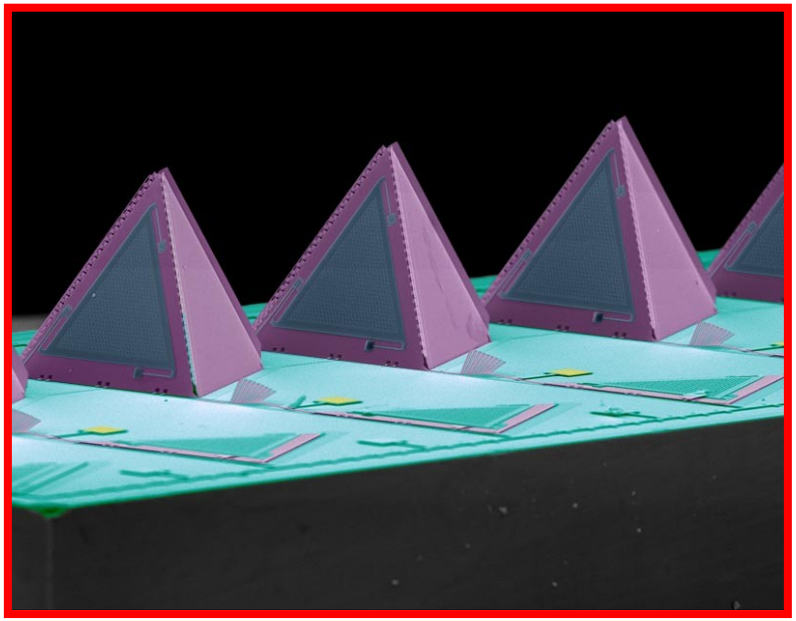

MEMS Vacuum Tubes



RF Inductors

# Bell Labs MEMS Micro-Microphones

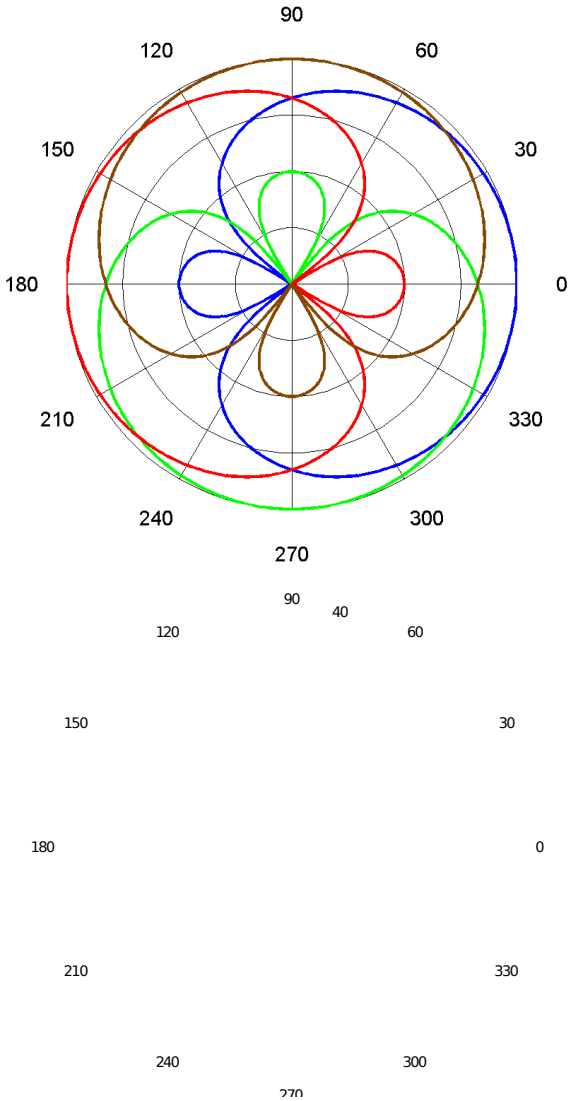


Not one, but many

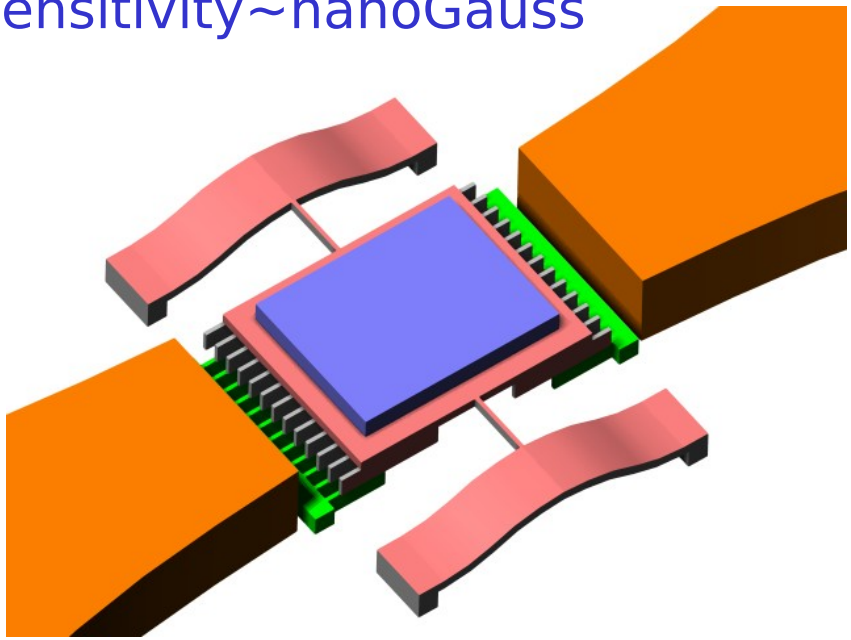
# Directional MEMs microphones

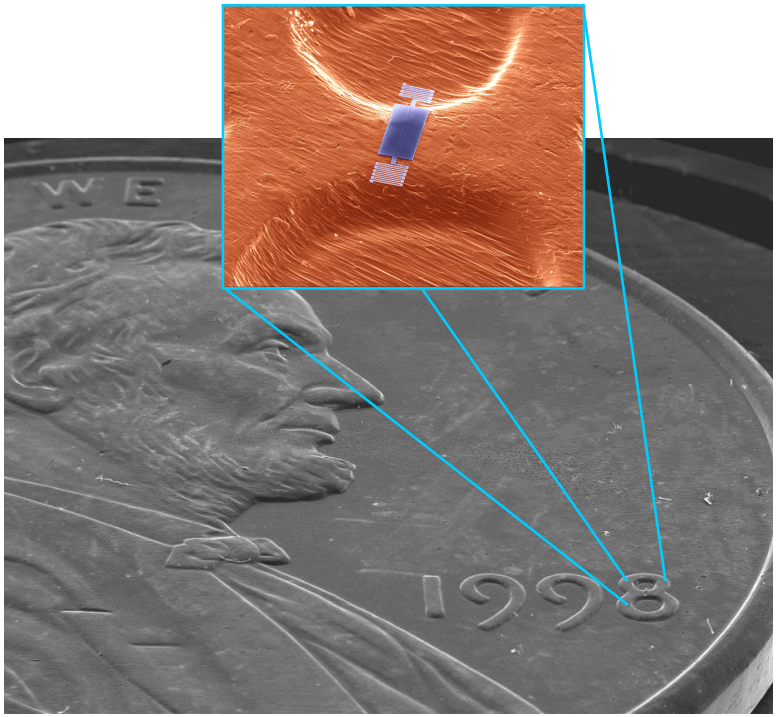
- **Unique combinations of velocity and pressure microphones with DSP enable:**
  - ***Multiple simultaneous output beams (enhance soldier sound localization while wearing helmet)***
  - ***Variable directivity (to zoom in or out for surveillance)***
  - ***Sound source direction finding (find sniper)***
  - ***Small, lightweight, and low power (wearable)***
  - ***Wideband (can be used with DSP to offer super-human audio listening range)***
  - ***Small scale offers inherent immunity to wind noise and vibration***
  - ***Small scale allows integration with other flow sensor technologies to further reduce sensitivity to wind noise.***



# Ultra Sensitive Nano Magnetometer

Sensitivity~nanoGauss



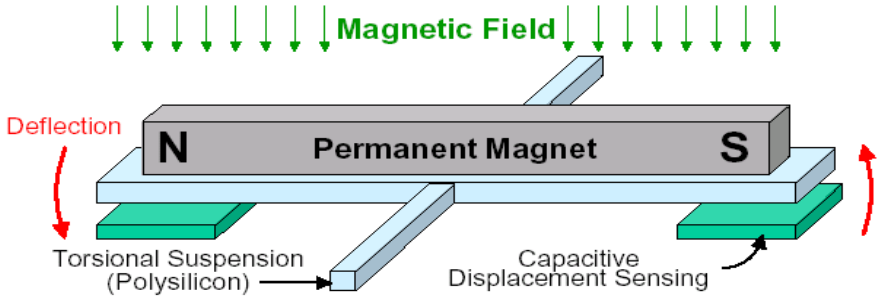



**Putting it all Together:**

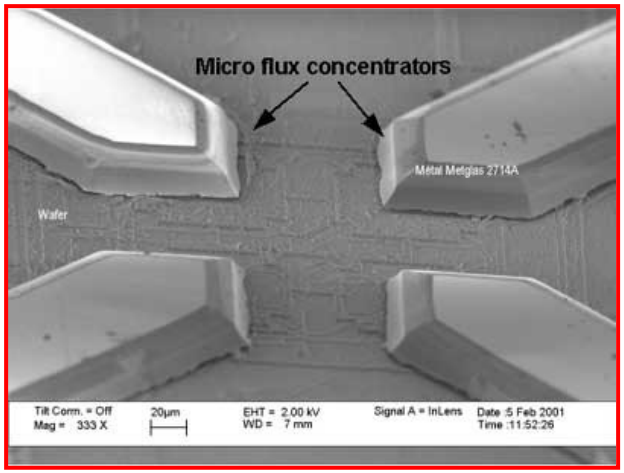
**An Integrated Solution to Supplement GPS**

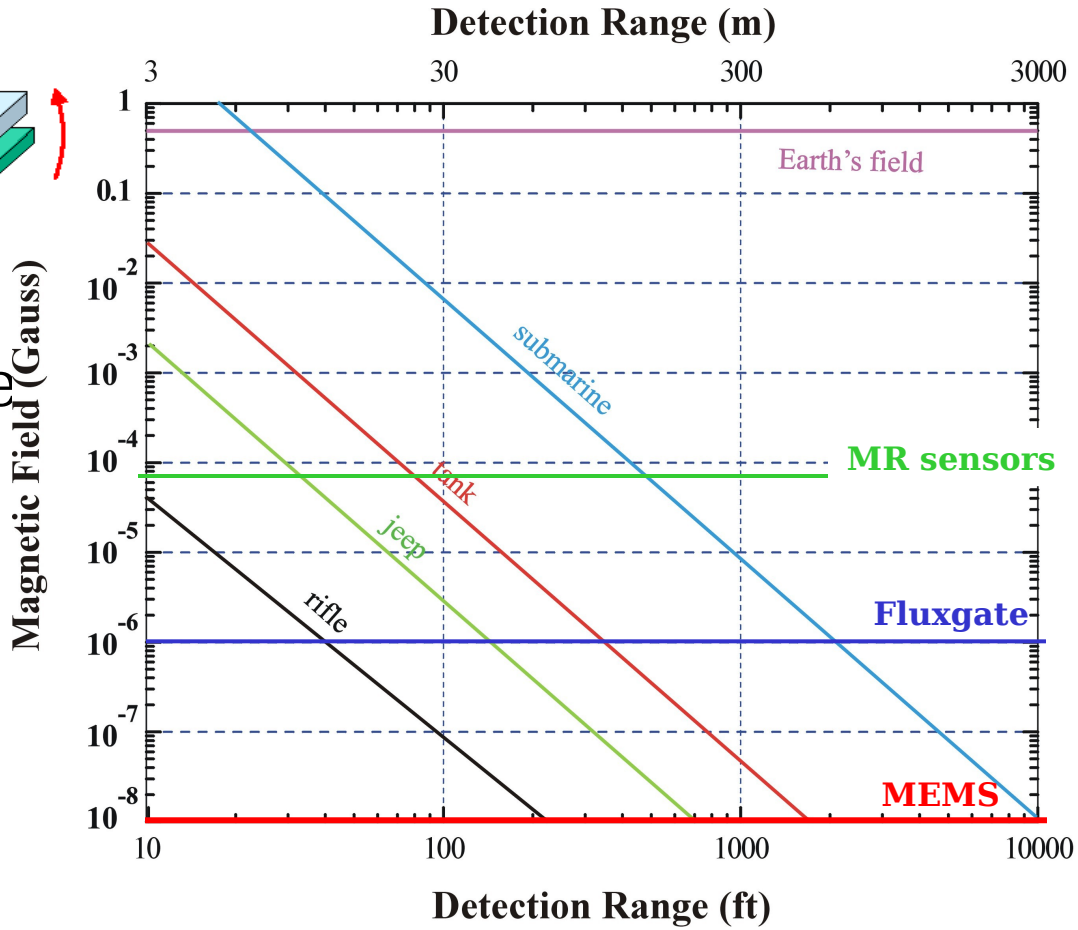
- MEMS Magnetometers to provide heading and tip/tilt information
- Inertial sensors to detect device movement
- All integrated onto a single silicon die to be robust, low cost, low power, small, light,.....

# High-Q torsional MEMS Magnetom

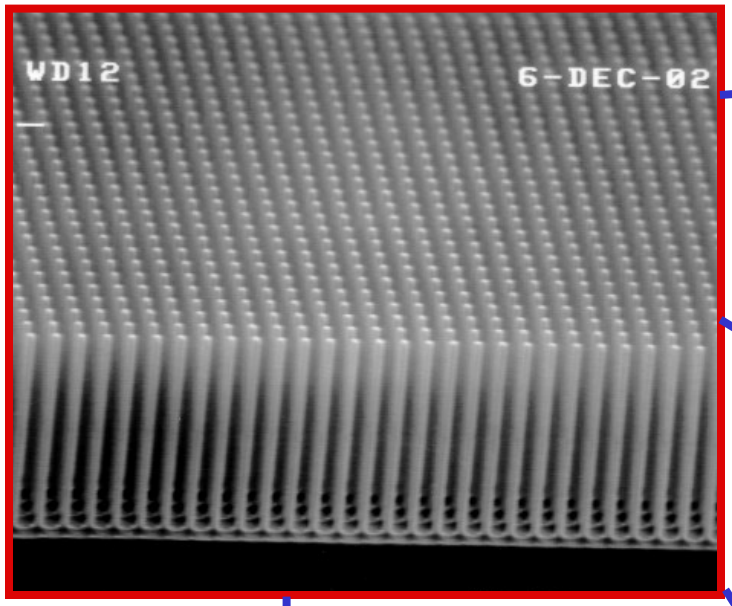


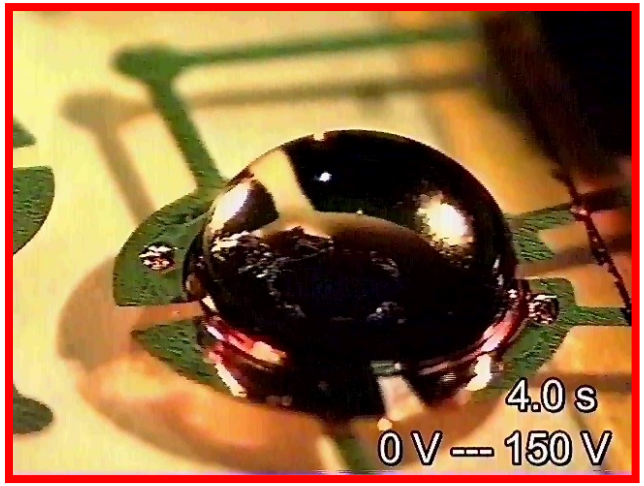

AC detection scheme



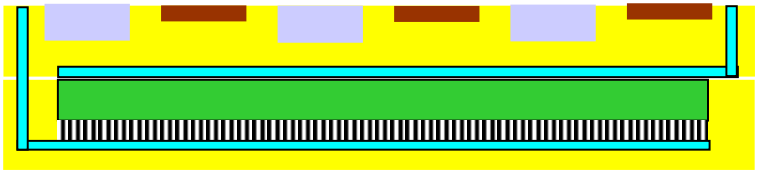



# NanoGrass Enables Many Unique Solutions

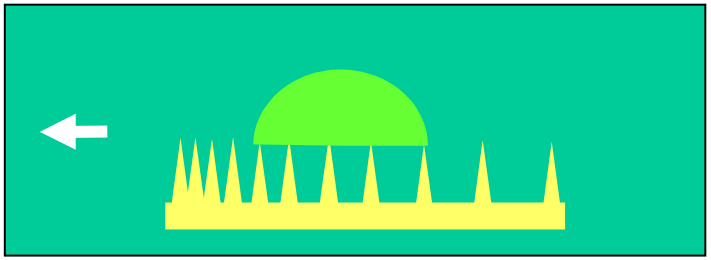


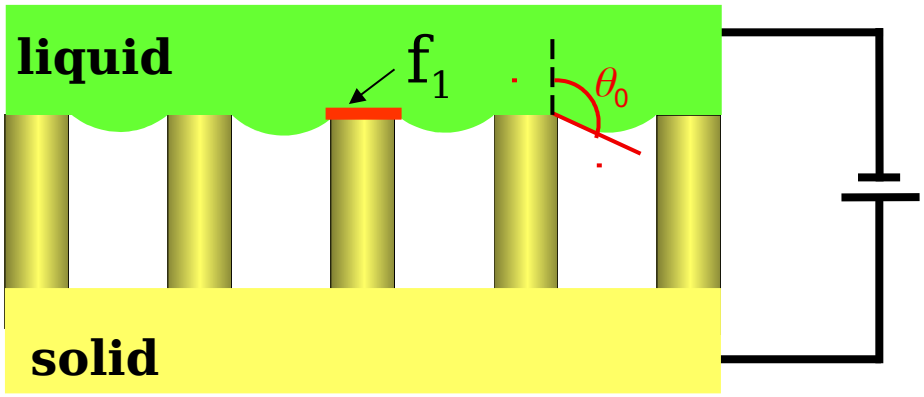

Liquid Lenses



Better Batteries

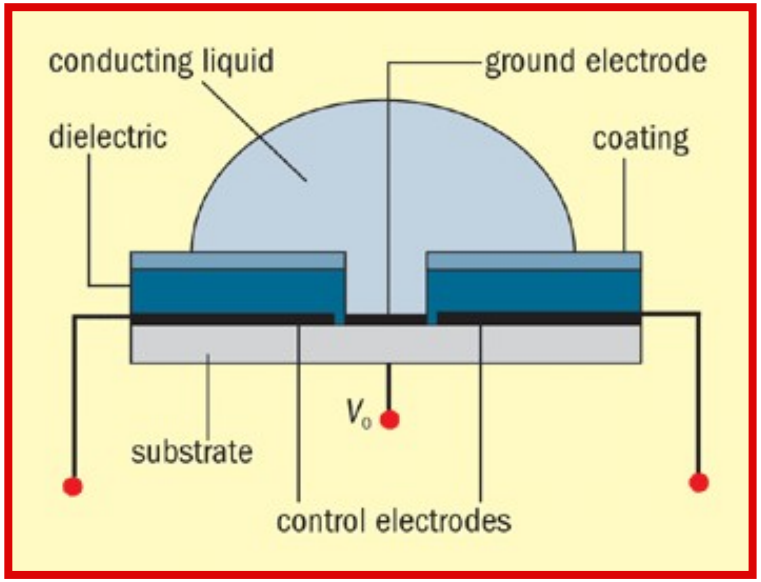


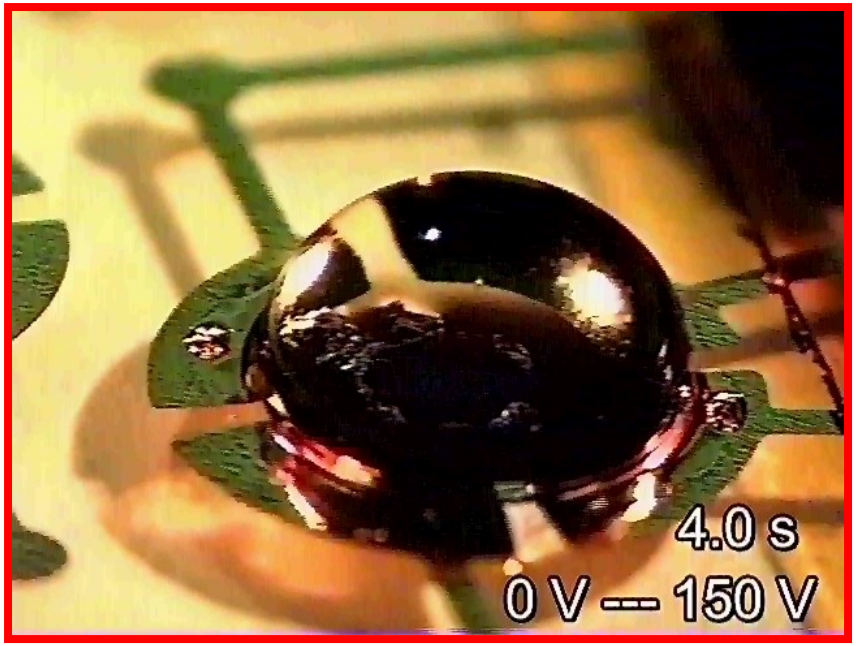
Droplet Chemical Factories




Smart Heat Sinks

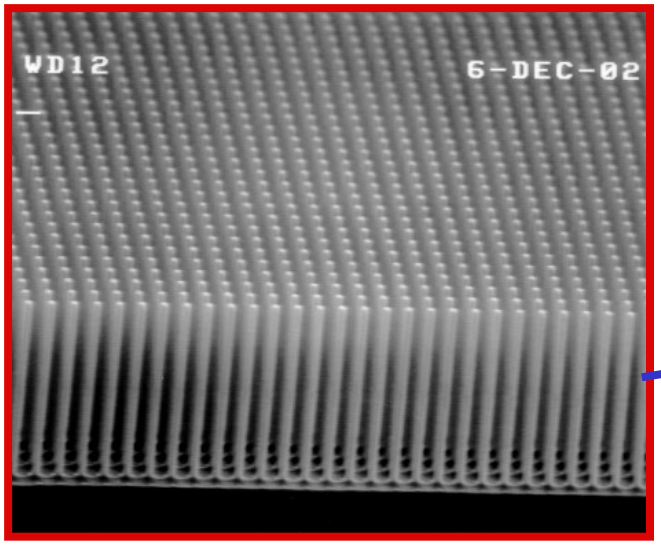
# Tunable Liquid Lens: An Electronic Cornea

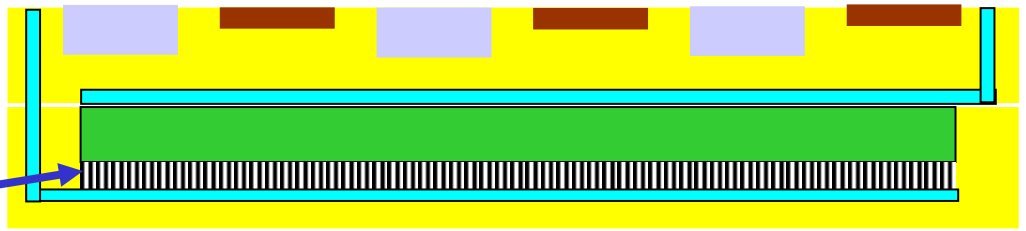



- Under electrical control one can tune the focus and the aim
- Small, low power, cheap. Can be used to stabilize an image.
- Can be applied in cell phones and disposable cameras

# NanoGrass->Better Batteries



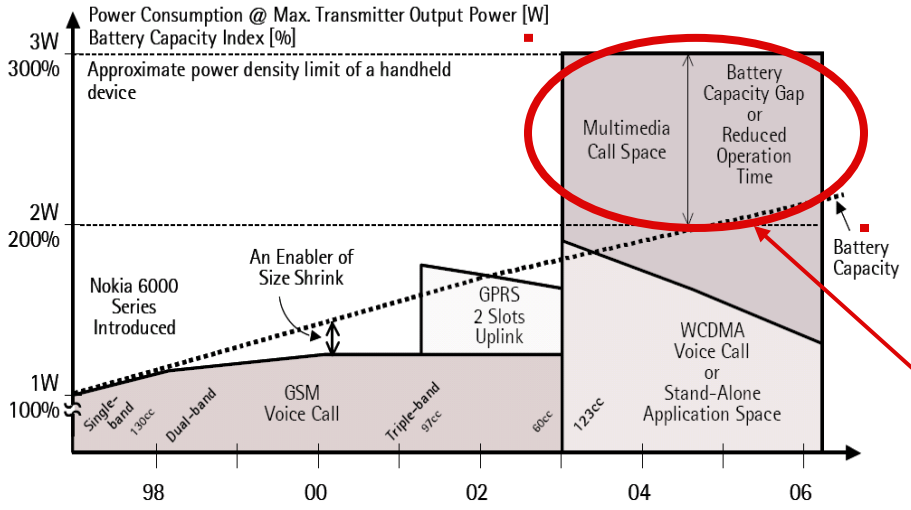
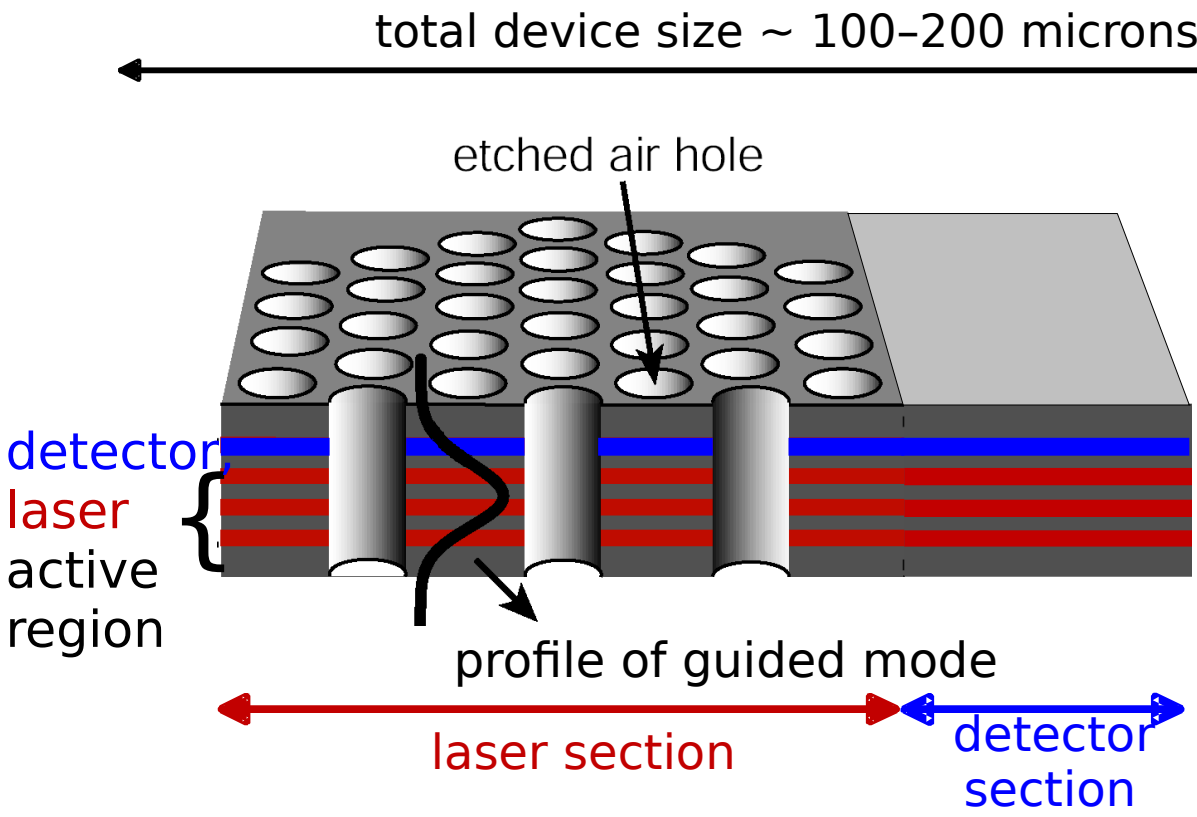



Figure 2 Illustrative development of battery capacity and power consumption in cellular phones.

- Nanobatteries: small, light, cheap, low self-discharge
- One of the few really new ideas in batteries in decades-traditionally a field with very slow progress (~10%/year)
- Next generation handheld devices require new battery technologies

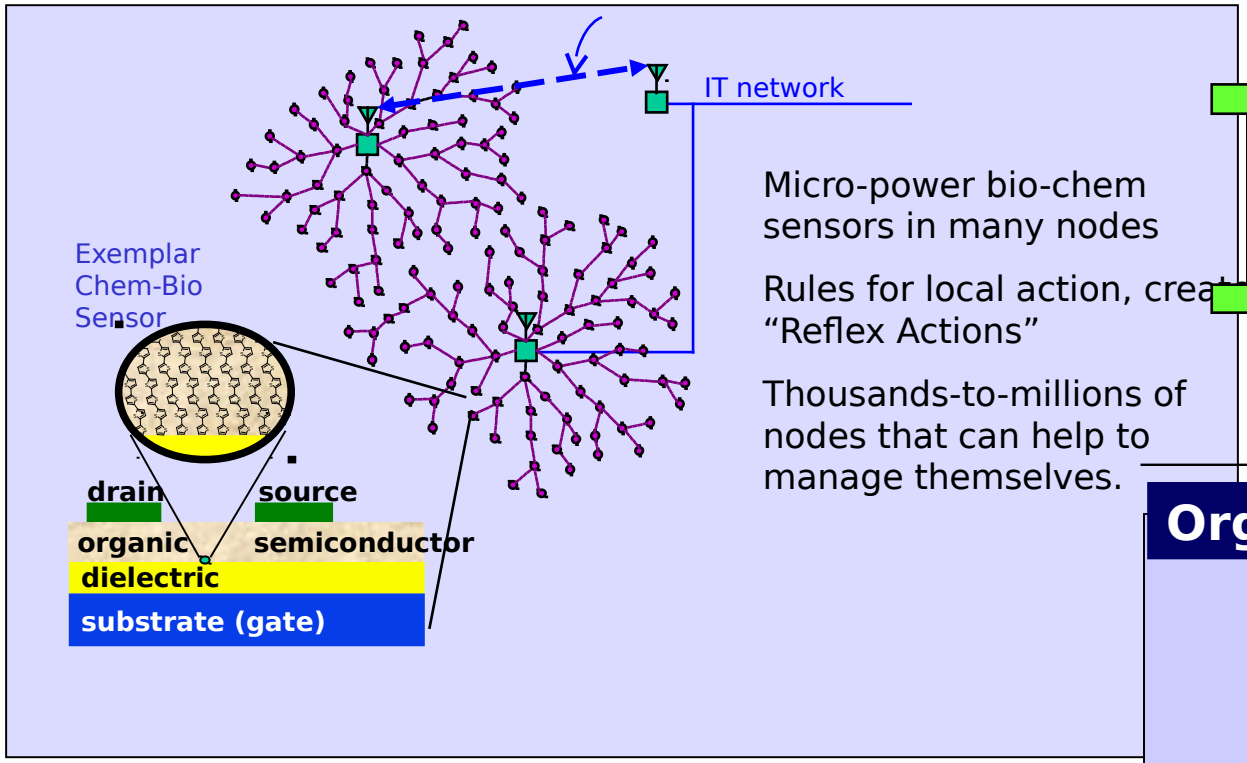
# Photonic Crystal Mid-Infrared Integrated Microsensor




Device has Demonstrated PPB Sensitivity

# Nanoscale Chemical Sensors via Plastic Electron

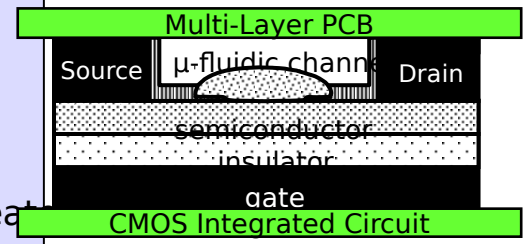
Design and integration of self-assembled nanostructured organic semiconductor materials and processes for “smart CBR” sensor networks



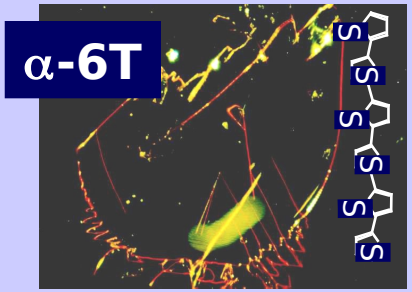

Micro-power bio-chem sensors in many nodes

Rules for local action, creat “Reflex Actions”

Thousands-to-millions of nodes that can help to manage themselves.

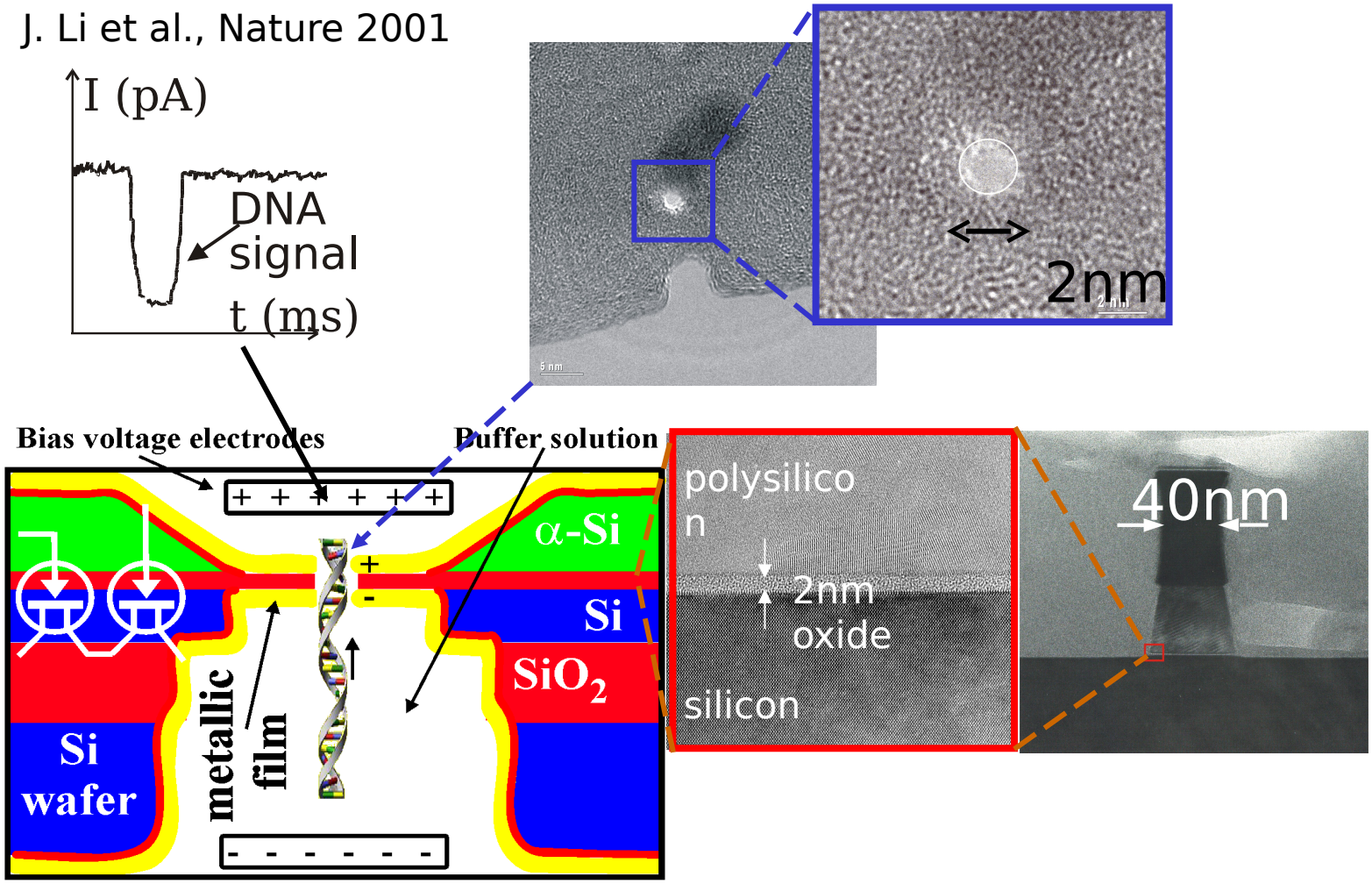



## Organic Semiconductors

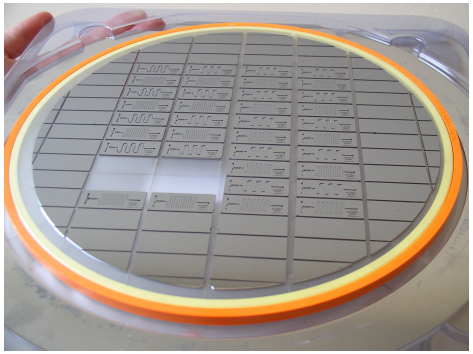


# Nanopores in Silicon: Real-Time DNA Analysis

J. Li et al., Nature 2001

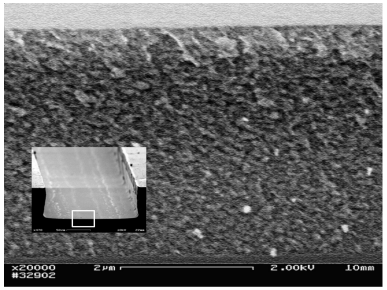


# MEMS MicroReactors-Chemical Factories on a Chip

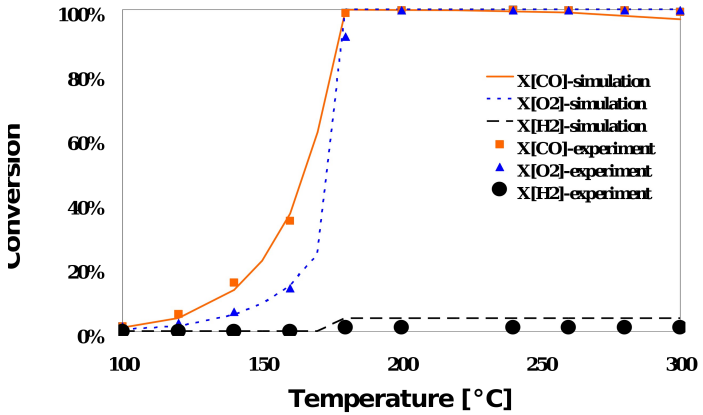


8-in. Si wafer, NJNC-Bell Labs


Short-channel reactor

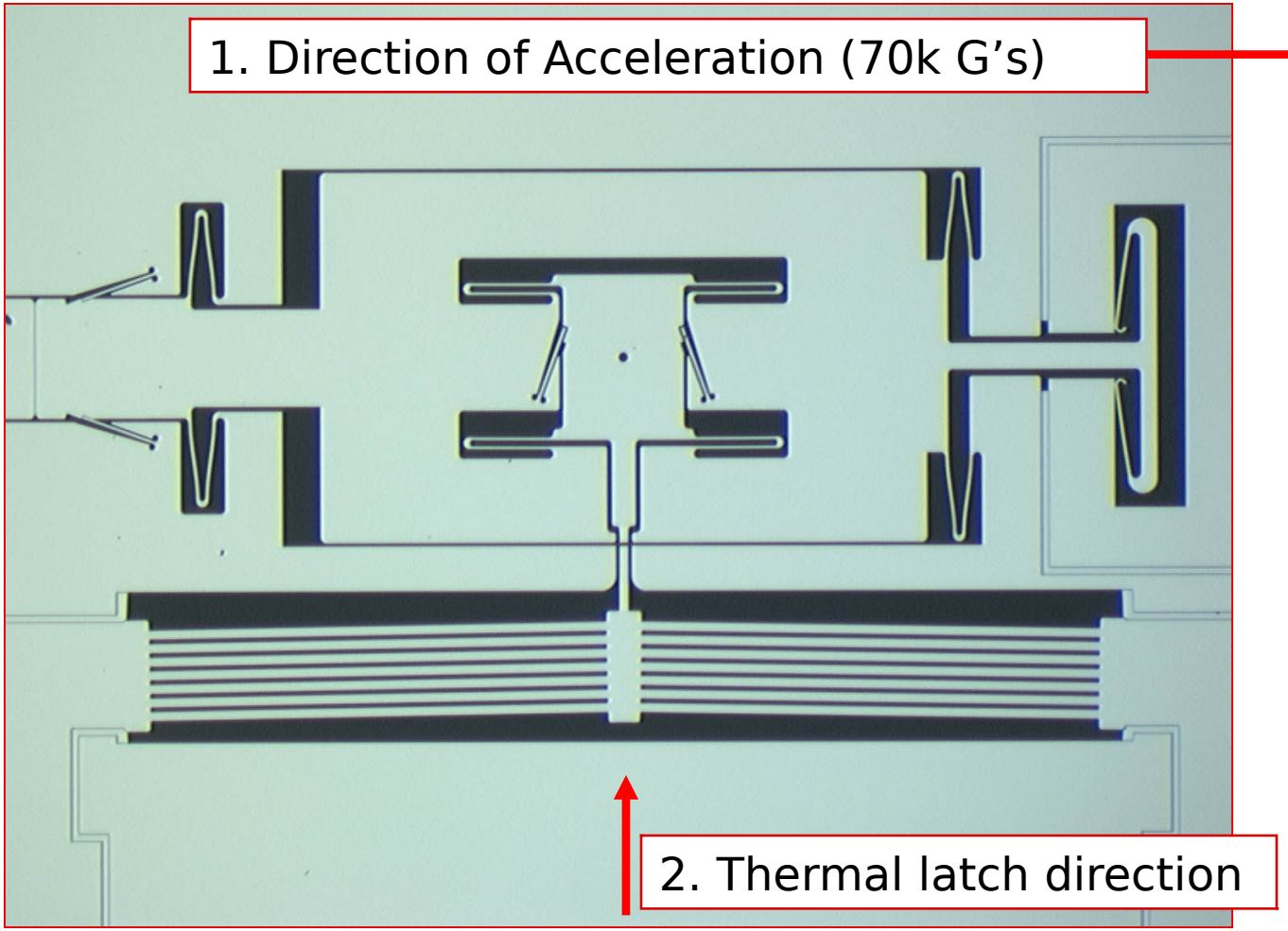


PrOx Thin-film catalyst




Short-channel reactor results

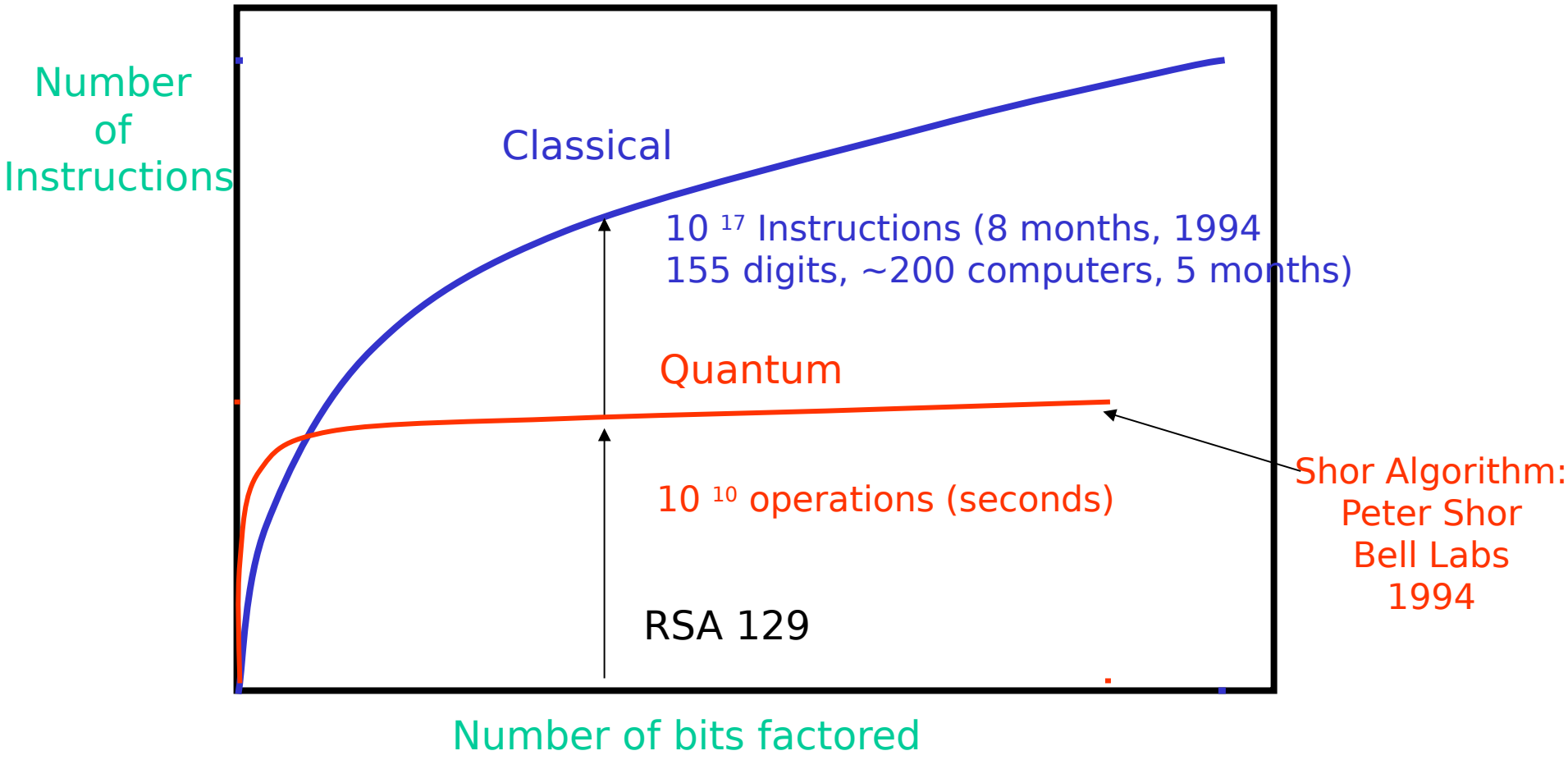
# Nano-Fuzes for Artillery Shells



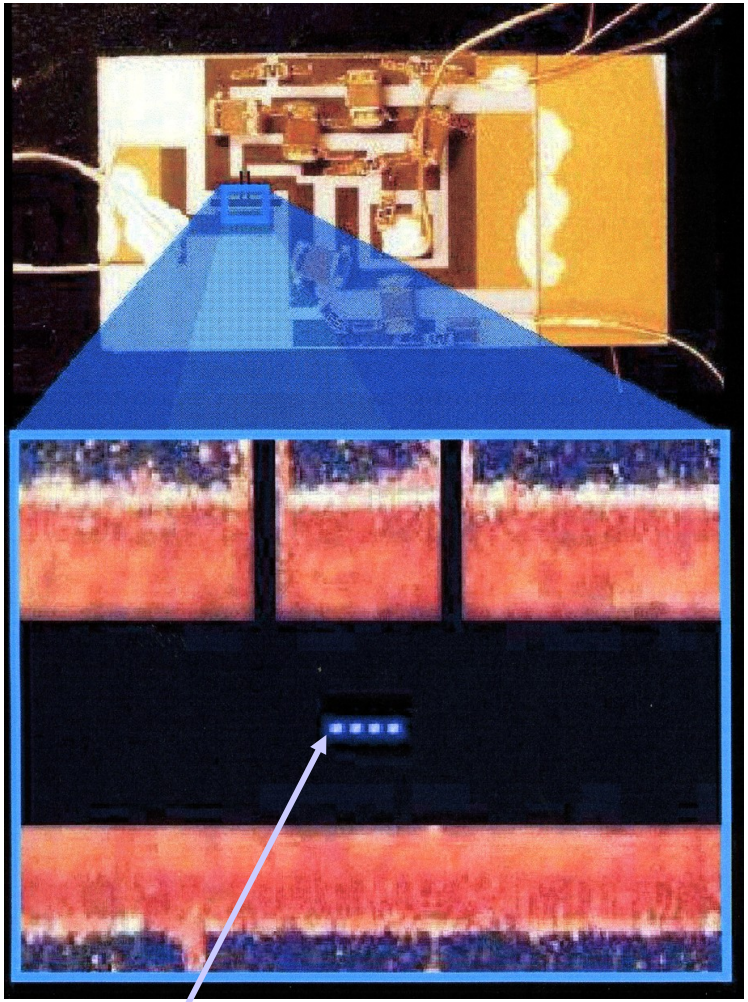

1. G-force set back latches shutter

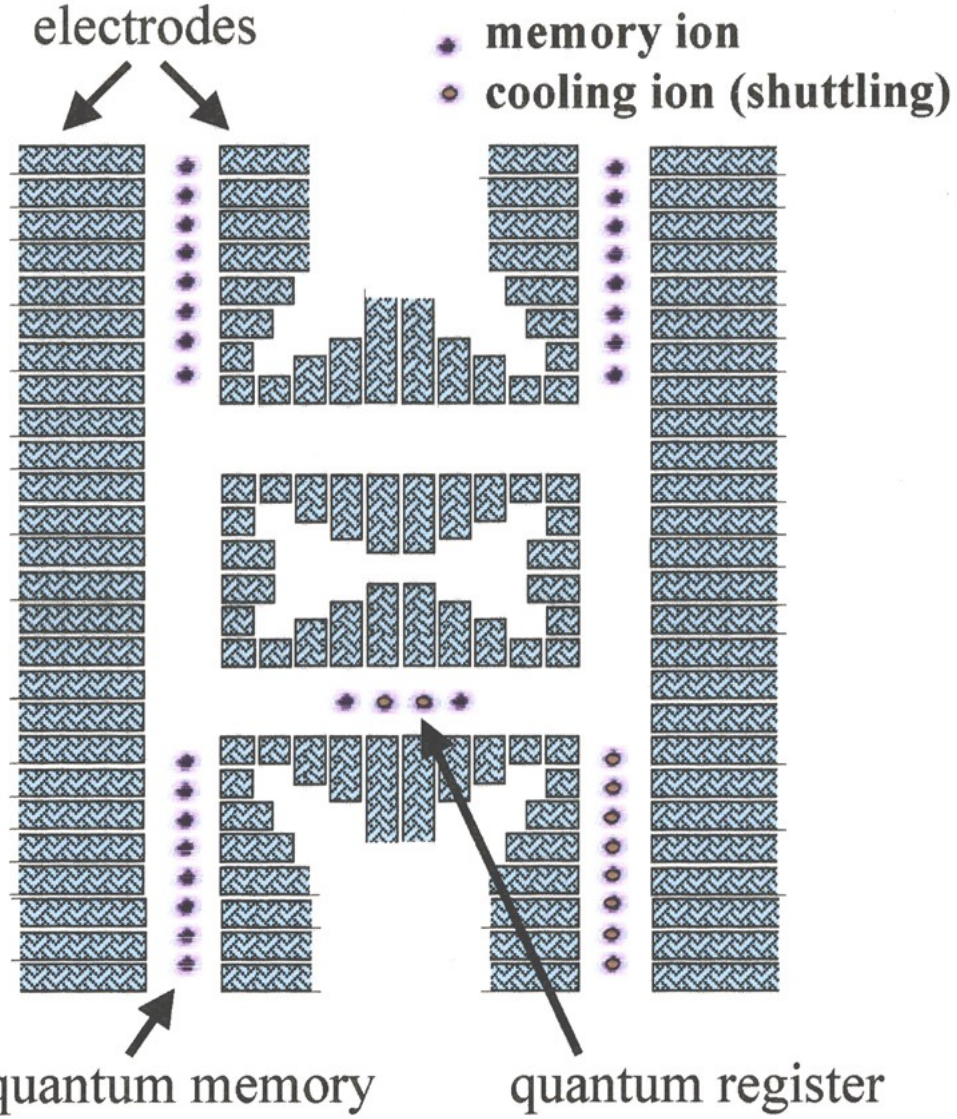
2.Shutter latched by thermal actuator under logic control

# Quantum Computing: A Revolution in the Making



# Quantum Computing Requires Nanotechnology



# Conclusions

- We are getting traction in nanotechnology with many commercial customers-the market is there today
- We think the reality will live up to the hype
- We have identified and are pursuing nanotech opportunities as part of the desire to have Bell Labs technologies create new businesses for Alcatel-Lucent and LGS
- We believe that Nanotechnology will provide a key edge for the warfighter